SUNRAY
SCIENTIFIC

Novel Magnetically Aligned Anisotropic Conductive Epoxy for Electronics Interconnection and Semiconductor Packaging

November 7, 2023

Ms. Madhu Stemmermann, CEO, SunRay Scientific Inc.

TOPIC OUTLINE

- Company Background
- INEMI Roadmap – Interconnect Challenges
- ZTACH® ACE – Technology and Background
- Potential Applications and Case Studies
- ZTACH® ACE R&D Roadmap
- Q & A

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Company SnapShot

Who We Are

- Innovative Advanced Packaging Materials & Solutions Provider
- US-Based, New Jersey
- Woman/Minority Owned

Key Features

- Patented Technology
- Green Technology
- SWaP-C benefits
- Unique capabilities for Advanced Packaging
- SMT Process compatible

Focus Areas

- Microelectronics Packaging
- 5G/6G RFIC Technology
- Secure Edge Computing
- AI Hardware
- Flexible Hybrid Electronics

Full Scale SMT Line - Prototyping & Testing and High-Volume Materials Manufacturing

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SUNRAY'S PRODUCT PORTFOLIO

Complimentary High-Performance Products

ZTACH® ACE

Anisotropic Conductive Epoxy – Thermal or UV Cure

- Fine – 100-200 microns pitch
- Ultrafine – <100 microns pitch (in development)

Conductive Ag Inks

Flexible, Stretchable Conductive Silver Inks

Encapsulation & Protection

UV Cured Flexible Encapsulants
UV and Thermal Cured Dielectrics

Epoxies

Highly flexible, low-temp cure, reduced Ag, Conductive Epoxies

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iNEMI 5G/6G Roadmap - Interconnect Challenges

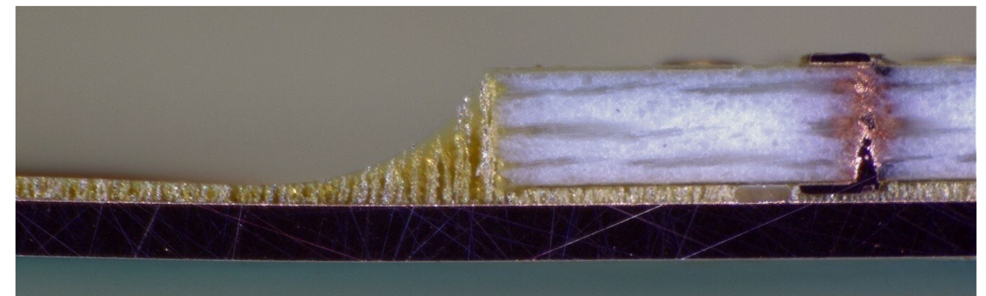
Solder Interconnect Challenges

- **High frequency losses**
  - Solder interconnects can contribute to signal loss at mmWave frequencies due to skin effect as well as mismatches in impedance.
- **Reliability challenges**
  - CTE mismatch between components joined by solder can lead to thermal fatigue and solder joint cracking over temperature cycling.
- **Pitch scaling**
  - Achieving fine pitch solder joints (<20um) needed for high I/O density is difficult with current processes.
- **Process limitations**
  - Solder reflow has limitations in terms of maximum temperature and number of reflows that components can withstand.
- **Thermal dissipation**
  - Solder does not provide an efficient thermal conduction path to remove heat from high power density components.
- **Re-work challenges**
  - Desoldering and reworking of dense micro-joints is extremely difficult.
- **Cost**
  - Relative to other interconnect methods, solder alloy material cost is high at smaller dimensions.

Alternative Interconnect Methods

- **Thermocompression bonding**
  - Uses pressure and heat to form direct metal-to-metal bonds without solder.
- **Hybrid bonding**
  - Combines dielectric and metal bonding for both electrical and mechanical connection.
- **Adhesive bonding**
  - Electrically conductive adhesives can be used for interconnects.
- **Magnetically aligned anisotropic conductors**
  - Self-aligning conductive particles enable solder-free bonding.
- **Compliant interconnects**
  - Provides both electrical and mechanical interface, absorbs thermomechanical stresses.

ZTACH® ACE



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ZTACH® ACE – MAGNETICALLY ALIGNED ANISOTROPIC CONDUCTIVE EPOXY

Magnetic alignment of highly conductive ferromagnetic particles randomly dispersed in an epoxy matrix

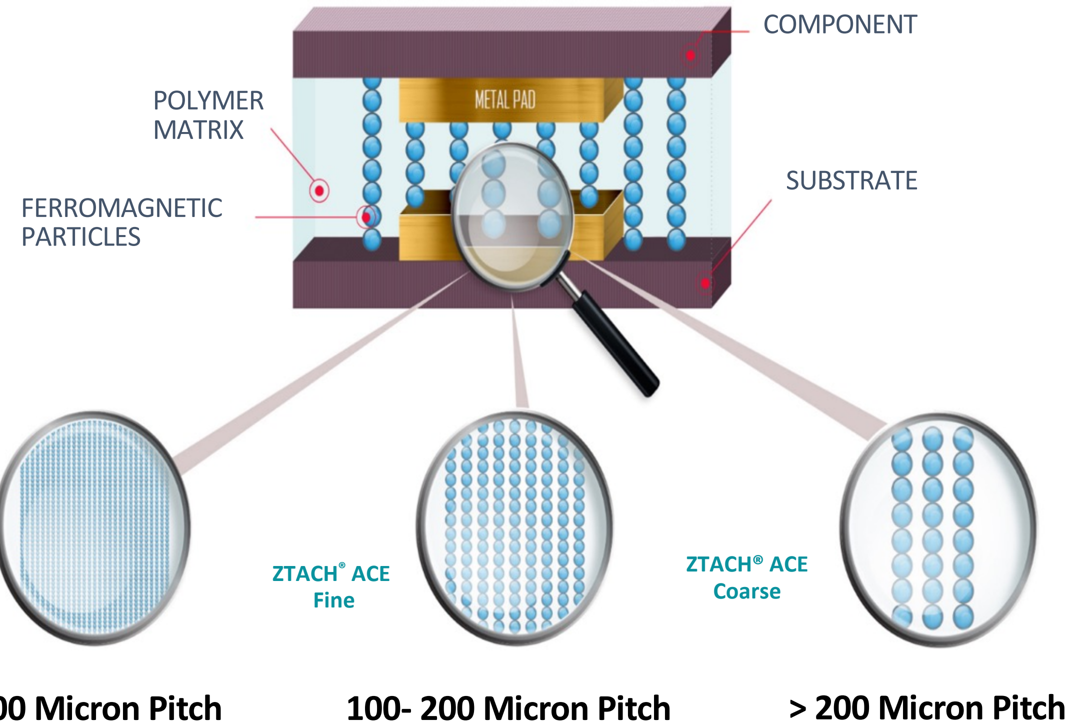
- Conductive column formation within 10 seconds
- Low temperature (80-180°C) curing, no pressure
- Outstanding structural rigidity, bond strength and reliability
- Electrical and Thermal conductivity (Z-Axis)

Scalable production via standard SMT processing

- Utilizing patented **ZMAG™** Magnetic Pallets

Improved Productivity, Environmentally Friendlier

- Single step assembly of mixed, multi components
- Elimination of separate underfill and/or encapsulation
- More environmentally friendly



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ZTACH® ACE - TECHNICAL ADVANTAGES

Fine pitch and non-planar morphology capabilities

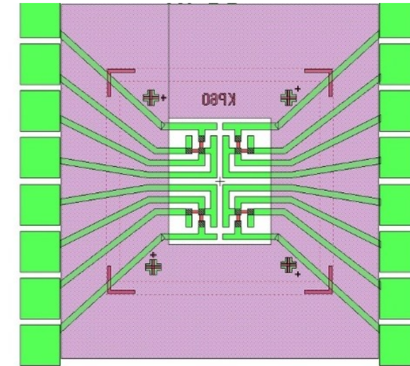
Multipath cooling

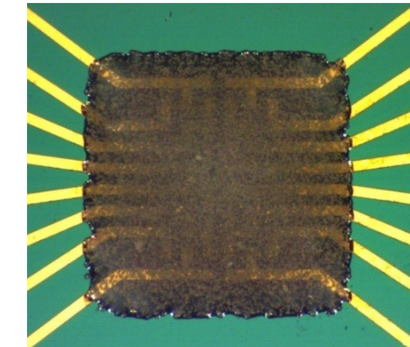
- Thermal dissipation via columns outside the pads

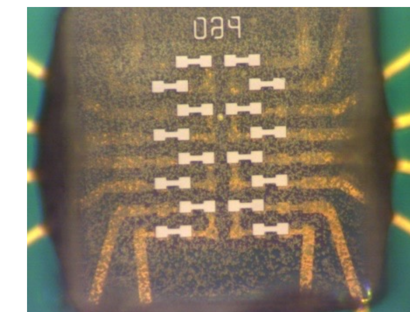
Demonstrated low-cost fine pitch/high yield

- Replacement for wire-bonding and flip-chip
- Suitable for advanced 3D packaging
- Eliminates stud bumps in many applications

ZTACH® ACE compatible with *Thin Die* - - lower stress processing







Top: **Target overlay of die-to-die bonding;** ***Middle:*** **ACE deposit before top die placement;** ***Bottom:*** **Post-bond, before z-axis alignment and cure.**

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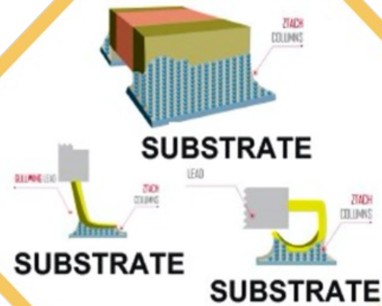
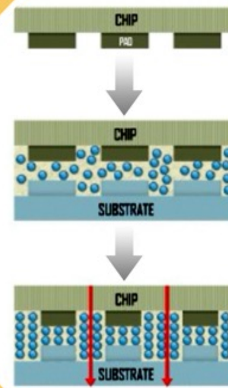
ZTACH® ACE - VERSATILITY OF THE INTERCONNECT SOLUTION

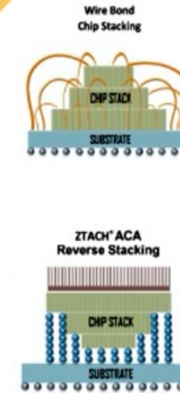
Leaded Components



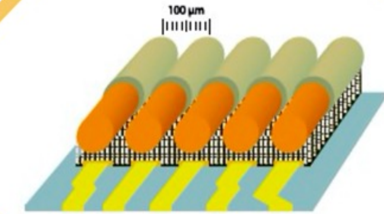
Flip Chip Bare Die



Chip Stacking



Ultra-Fine Wire Attach



Markets

Medical/Wellness
Automotive
Consumer Electronics
MIL/Aerospace
Industrial
White Goods/Appliance
Expanding

Applications

Flexible Hybrid Electronics
Wearable Diagnostics
Smart Clothing
RFID tags & labels
Printed Sensors
Wireless Communications
Flip-Chip/Die-Attach
Semiconductor Packaging

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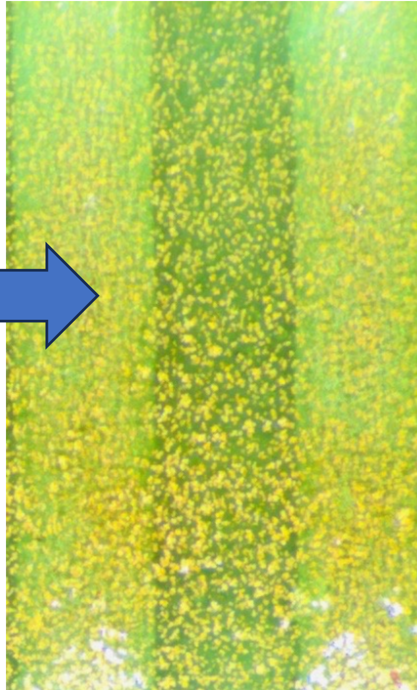
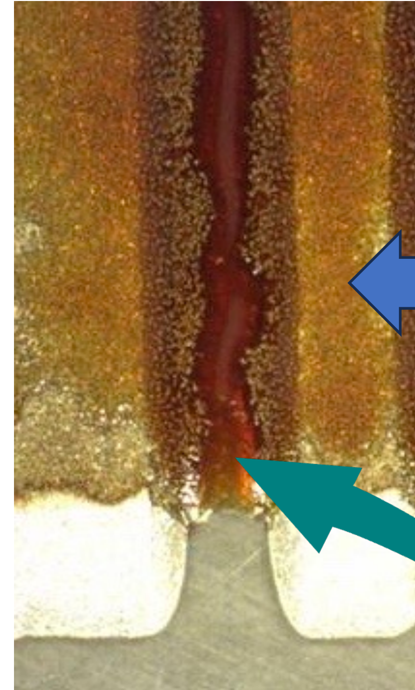
ZTACH® ACE - Improved Conductivity through Column Concentration

Without
Nickel Layer





With Nickel
Layer

Allows for material separation further eliminating short circuiting and creating a higher density of z-axis connections per pad.

- Added Ni interposer layer to substrate prior to ZTACH® ACE application
- Concentrates column formation when exposed to magnetic field
- Decreases surface resistance & concentrates higher density of columns on the pads

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iNEMI 5G/6G Roadmap - ZTACH® ACE Addressing Challenges

Areas of Concern	Potential Issue	ZTACH Value Proposition to Address Issue
Thin Substrate	Reducing substrate thickness essential to minimize loss between ICs and antennas. Requires advanced thinning and handling. CTE Mismatch during higher temperature curing	• Requires no pressure and low-temperature assembly. • A successful track record in Flexible Hybrid Electronics (FHE). • Accommodates non-conformal shapes without causing connectivity issues.
Surface Finish	Suitable metallization needed that supports fine features and has low conduction losses.	• Utilizes Ni-Au UBM for fine feature finishes, enhancing ZTACH column concentration. • No stud bumps needed
Double Sided Assembly & Die Embedding	Needed for thermal management and 3D integration but adds process complexity.	• Cured ZTACH remains unaffected during further thermal processes. • Facilitates effective embedding and double-sided assembly.
3D & Heterogeneous Integration	Integrating different components like ICs, passives, antennas is complex and requires co-design.	• Handles various lead geometries, device sizes, and pitches. • Requires open aperture printing with no precision stencil. • Eliminates the need for solder bumping in Chip Scale Package (CSP) and Wafer-Level Packaging (WLP).
Thermal Management	Providing effective heat dissipation and spreading for high density components.	• Z-Axis columns are electrically and thermally conductive in z-axis.
Reliability Challenges	CTE mismatch between components joined by solder can lead to thermal fatigue and solder joint cracking over temperature cycling.	• Proven performance in thermal aging, T&H aging, shear loading, Cryogenic conditions, RAD hardness testing, and RF performance. • ZTACH ACE matrix can be customized to match application-specific requirements.
Solder Process Limitations - Temperature	Solder reflow has limitations in terms of maximum temperature and number of reflows that components can withstand.	• Cures at temperatures ranging from 70-180°C, with UV-curable options available. • Proven minimal degradation through multiple tin-lead and lead-free reflow processes.

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ZTACH® ACE - FULLY SCALABLE MANUFACTURING USING EXISTING SMT LINES

More in the next slide

Material Preparation

Weigh and Mix

Material Placement

Stencil and Dispense

Component Placement

SMT Pick-and-Place System

Alignment & Cure

ZMAG™ Magnetic Pallet, Batch Oven, Reflow Oven, UV Batch, Roll-to-Roll UV (in dev)

➢ ZMAG™ Magnetic Pallet is Introduced During the Curing Process. It easily Integrates into In-Line or Batch Oven

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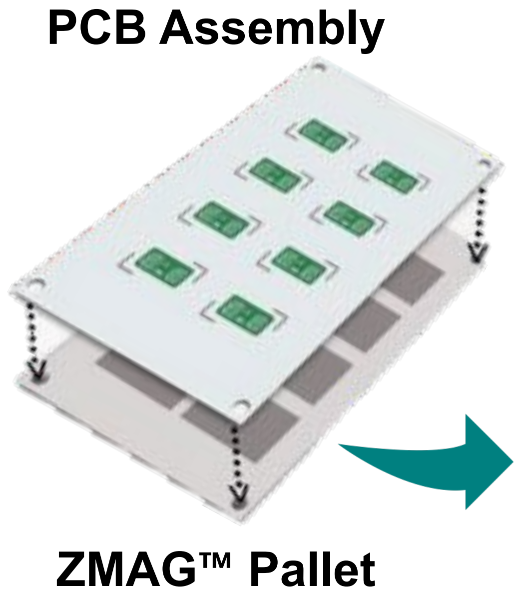
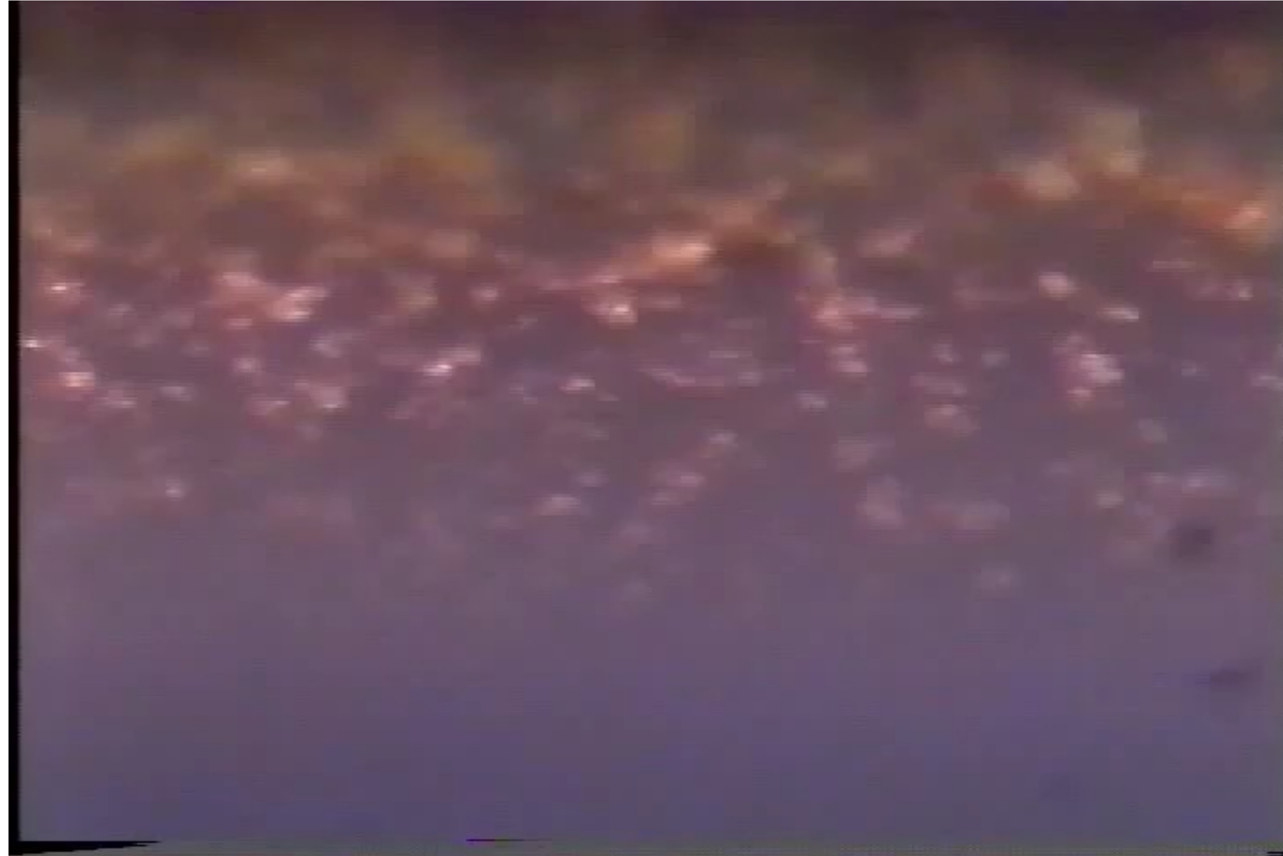
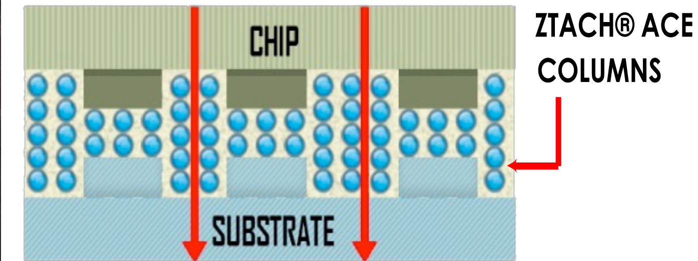
ZTACH® ACE - COLUMN ALIGNMENT PROCESS

PCB Assembly



ZMAG™ Pallet





ZTACH® ACE
COLUMNS

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PERFORMACE OF ZTACH® ACE:

TYPICAL PROPERTIES OF UNCURED ADHESIVE	
PROPERTY	**SPECIFICATION**
Viscosity at RT Brookfield RV #6, 10 rpm	50,000-55,000 cP
Density	1.35 g/cc
Binder	Modified Epoxy/Resin Complex
Filler	Conductive Particles
Filler Concentration	10-70% by Weight
Stability of Raw Material	6 Months at 25˚C

TYPICAL PROPERTIES OF CURED ADHESIVE	
PROPERTY	**SPECIFICATION**
Glass Transition Temperature (Tg)	110-140˚C
Coefficient of Thermal Expansion (CTE) Below Tg	65 ppm/˚C
Shrinkage	< 5%
Thermal Conductivity	1.5 - 2 W/m-K
Connection Resistance	7 – 20 mOhm
Insulation Resistance	>10^{11} Ohms
Elastic Modulus (ISO 527-2)	500 N/mm2
Operating Temperature	Max. 100˚C
Breaking Stress Under Shear	6.8×10^6 N/m^2 (a) 1.7×10^7 N/m^2 (b)

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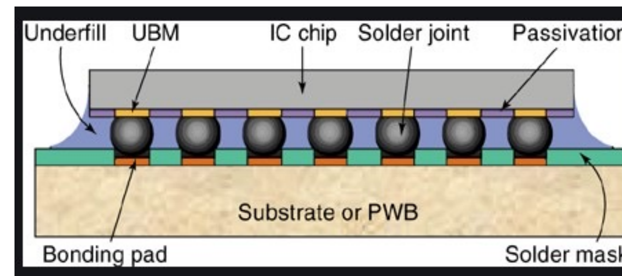
ZTACH® ACE AS ITS OWN INTERCONNECT & UNDERFILL

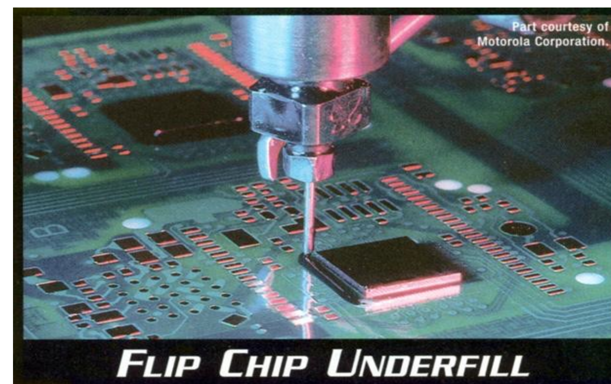
ZTACH® ACE Benefits:

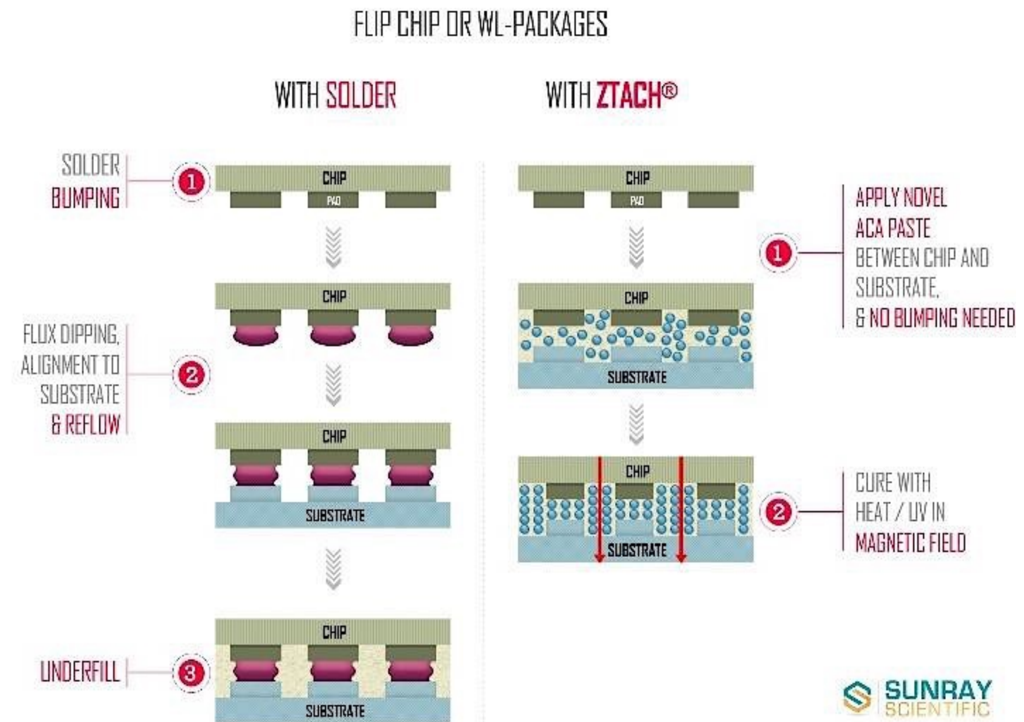
- Eliminate bumping on multiple levels
- Low temp processing
- Reduced Coefficient Thermal Expansion (CTE) mismatch / warpage
- No additional underfilling
- Enables integration of subminiature sized passives <01005

ZTACH® ACE: Eliminates need for separate underfill process for flip chip & wafer level processes



Flip Chip Requires Underfill





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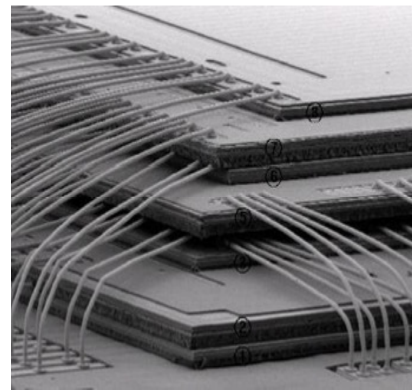
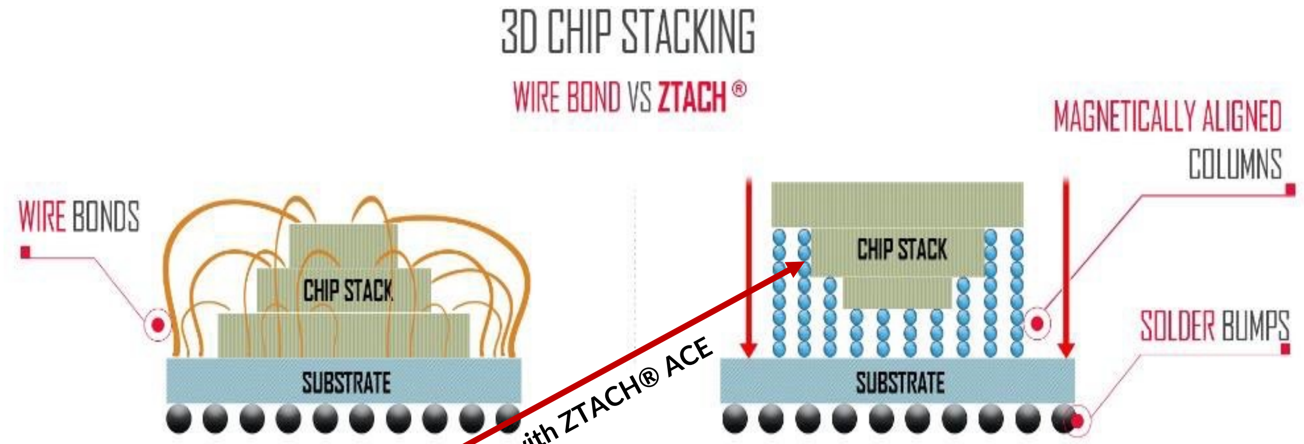
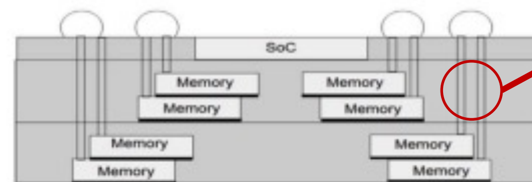
ZTACH® ACE AS A POTENTIAL WIRE BOND REPLACEMENT

ZTACH® ACE Benefits:

- Eliminates wire bonds
- Reduces parasitics
- Enables miniaturization
- Low SWAP-C
- Greater thermal dissipation







Possible Interconnect with ZTACH® ACE In memory applications

Fan-Out Multi-Stack integration (TSMC MiM). (WLP Chapter Figure 38, and ECTC 2019)

Heterogeneous Integration Roadmap Chapter 1, Page 8

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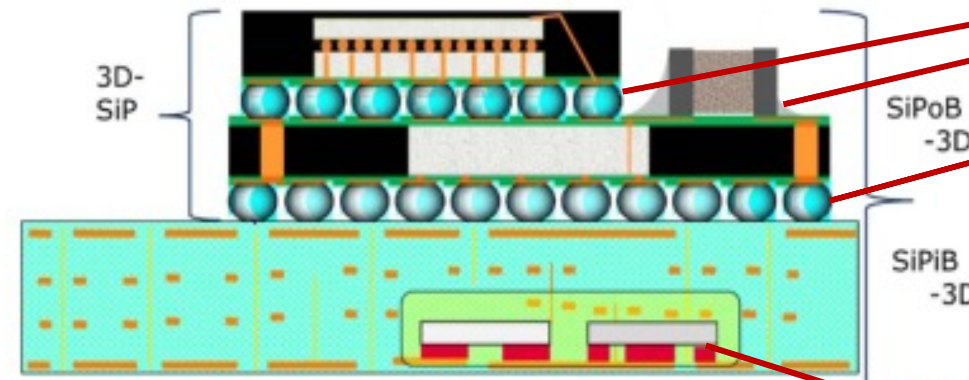
ZTACH® ACE AS A POTENTIAL SYSTEM IN PACKAGE (SiP) INTERCONNECT MATERIAL

ZTACH® ACE Benefits:

- Eliminates bumps, C4 and BGA balls
- Lower temperature processing
- No pressure bonding
- Simultaneous bonding of multiple levels of package
- Through Silicon or Glass Via filling enabling multilayer interconnection

ZTACH® ACE: Enables the merger of different components and functionalities into one package, using one material, at multiple levels including embedded devices



Multi-Level Representation of an SiP differentiating SiP-on-Board (SiPoB) and SiP-in-Board (SiPiB) [courtesy INFINEON AG]

Heterogeneous Integration Roadmap 2021, Chapter 21, Page 2

Possible Interconnect with ZTACH® ACE Elimination of solder bumps and solder-based attach. Creating thinner bond-line thicknesses

Embedded devices can also be attached with ZTACH® ACE

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ZTACH® ACE AS POTENTIAL FOR Cu-Cu HYBRID BONDING

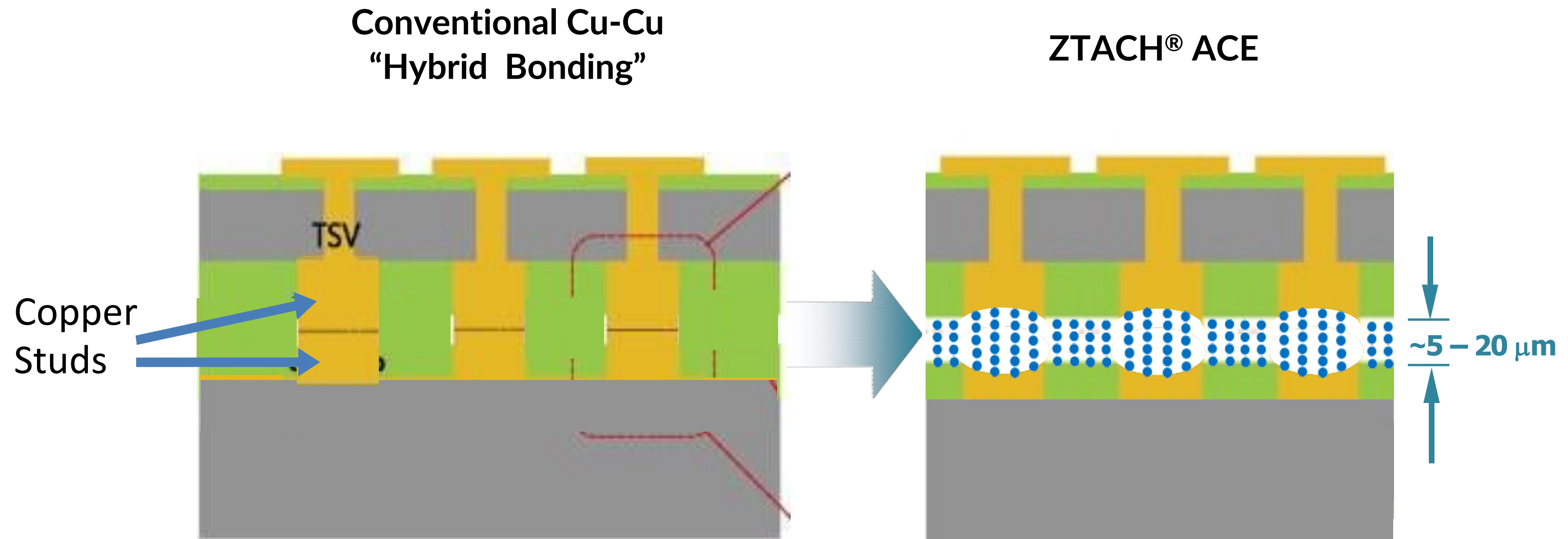
ZTACH® ACE Benefits:

- No planarization required
  - Reduced particle induced yield hits
  - Plasma activation not required
- No pressure and high temperature required in bonding

* **Babak Sabi, Intel @ IMAPS 2020**

"One small particle and the die is gone … we need to have integrated,
fab-like assembly tools where we keep everything clean."

ZTACH® ACE: Demonstrated ability to interconnect non-planar surfaces



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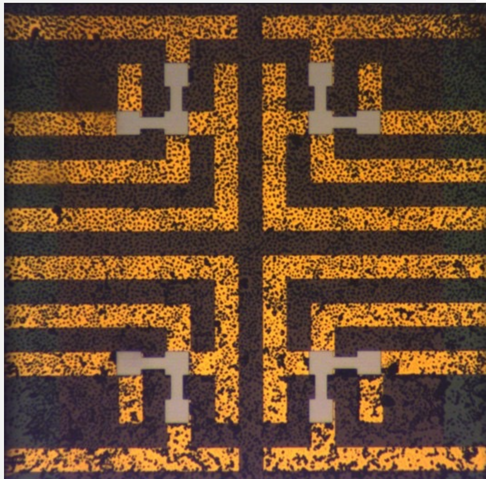
CASE STUDY: HIGH-DENSITY FINE PITCH WAFER-LEVEL INTERCONNECTS

Objective:

Bond wafer-level array test vehicles

- Achieve low contact resistance & no electrical leakage between adjacent conductive columns



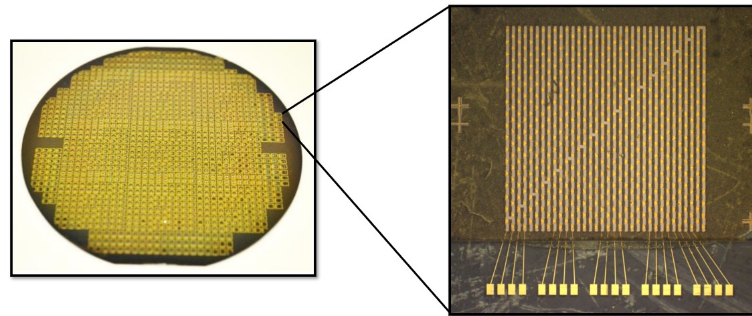
Top view of ACE conductive particles connecting die-to-die

Approach:

Each daisy chain has defined number of contact pads, increasing left to right

ZTACH® ACE is stenciled/ dispensed; sandwiched between the substrate and top die

ZTACH® ACE is spread across the entire die bond region



50µm Pitch Daisy Chain Test Structure

Accomplishments on high density fine-pitch die:

- 150-Micron: Cumulative Yield 100%
- 100-Micron: Cumulative Yield 97%
- 50-Micron: Cumulative Yield 72%
- High-Temp Storage - good performance up to 125C (100-micron) & 165C (50-micron)
- Thermal Cycling (-50C to 50C) - Excellent performance through 1000 cycles
- Die Shear Testing - Exceptional bond strength between Si-Si and Quartz-Quartz assemblies
- 85C/85%RH Testing - Exceptional resistance stability over 7 days
- Cryogenic (-55°C to 85 °C) exposure & radiation hardness performance is excellent

Funded By: Department of Energy, “Phase I & II Enhanced Interconnects”

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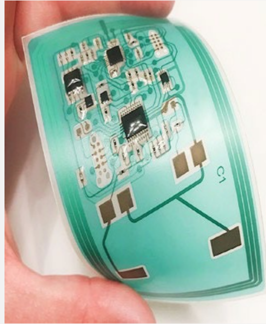
CASE STUDY: FHE - LIGHTWEIGHT INTERCONNECTS FOR DYNAMIC AEROSPACE ENVIRONMENTS

Objective:

Develop conformal antennas demonstrating **ZTACH® ACE** as robust, scalable Z-Axis inter-connect solution for RF systems, (flexible, lightweight, ultra-thin)



- Achieve robust, low loss, high-isolation, compact & tightly integrated interconnects: 1-40 GHz frequency range
- Demonstrate performance capabilities by mounting to wings of UAV aircraft (Condor)

Funded By: AFWRX, "Lightweight Electrical Interconnects for Aerospace Environments"

Approach:

Developing test coupons and conformal antenna design using semi-rigid substrate for RF testing

SunRay Scientific executing interconnect packaging with **ZTACH® ACE**

- Previously demonstrated positive performance: up to 90GHz
- Demonstrated radiation hardness & cryogenic temperature capability
- Performing characterization & testing (electrical conductivity, thermal cycling, mandrel bend, tensile testing, humidity testing)

Accomplishments:

- Microstrip coupons validated **ZTACH® ACE** RF performance (equivalent to standard bonding techniques)
- Developed a process to bond semi-rigid PCBs with **ZTACH® ACE** achieving 100% continuity & low contact resistance
- Rheological testing revealed comparable behavior compared to reference commercial epoxy
- Conformal antenna designed
- Developed custom tooling to allow for automated population on standard SMT line without reconfiguration.

Next Steps:

- Develop conformal antenna assemblies, conduct reliability and functional testing
- Design and setup **ZTACH® ACE** assembly process for on-site testing
- RF Performance testing

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LOCKHEED MARTIN

RIT Rochester Institute of Technology

CASE STUDY: FHE - RELIABLE, CONFORMABLE, WEARABLE SENSORS

Objective:

Expand and advance R&D efforts of FHE to mature core material technology for processability, reliability, and robustness in **e-Textile wearable & conformable electronic sensor products**

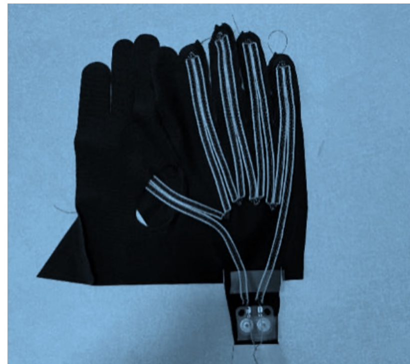
Funded By: AFWRX "SBIR expand R&D of flexible hybrid electronics" AFWRX Phase II "Military Wearables"

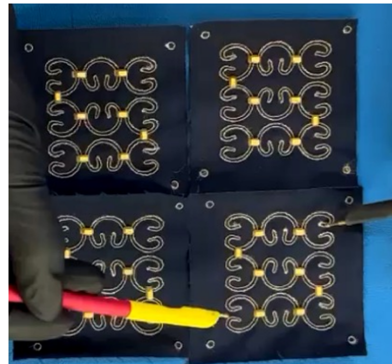
Approach:

Update design, build, integration, and testing of a First Responder Blanket / e-Textile System to measure ECG and respiration rate

Conduct additional testing to establish critical user database relative to military applications & environments

Figure 1-3: lessons learned from work with e-textiles





Accomplishments:

Expanded role of **ZTACH® ACE** beyond interconnect technique:

- Use with Human Systems Integration (HSI) e-textile wires showed <0.5% impedance variation during 80°C swing thermocycling, <5% variation in resistance, and <10°C thermal load
- Demonstrated fatigue cycling for 100 cycles at 30% strain amplitude without losing conductivity & no visible cracks
- Under HSI's assessment & testing technology performed very well in conduction of higher currents & under thermal stress

Demonstrated material set capability

Next Steps:

- Identify high volume manufacturing process for E-textile system
- Conduct trial of attaching various components to flexible board
- Assess both UV & Thermal cure **ZTACH® ACE**
- Optimize formulations & manufacturing process

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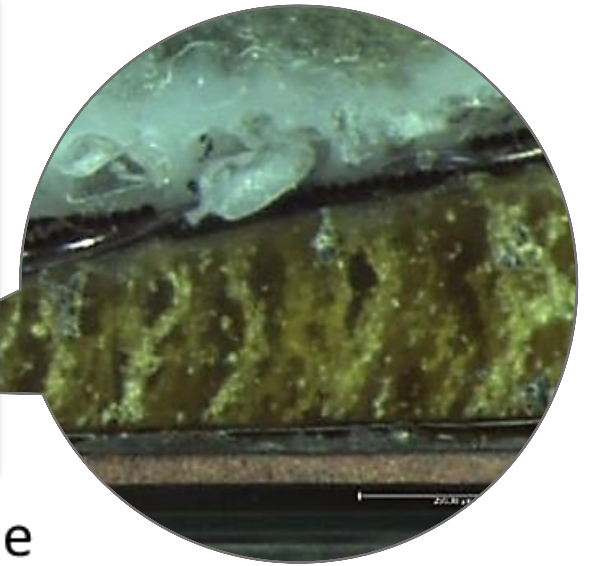
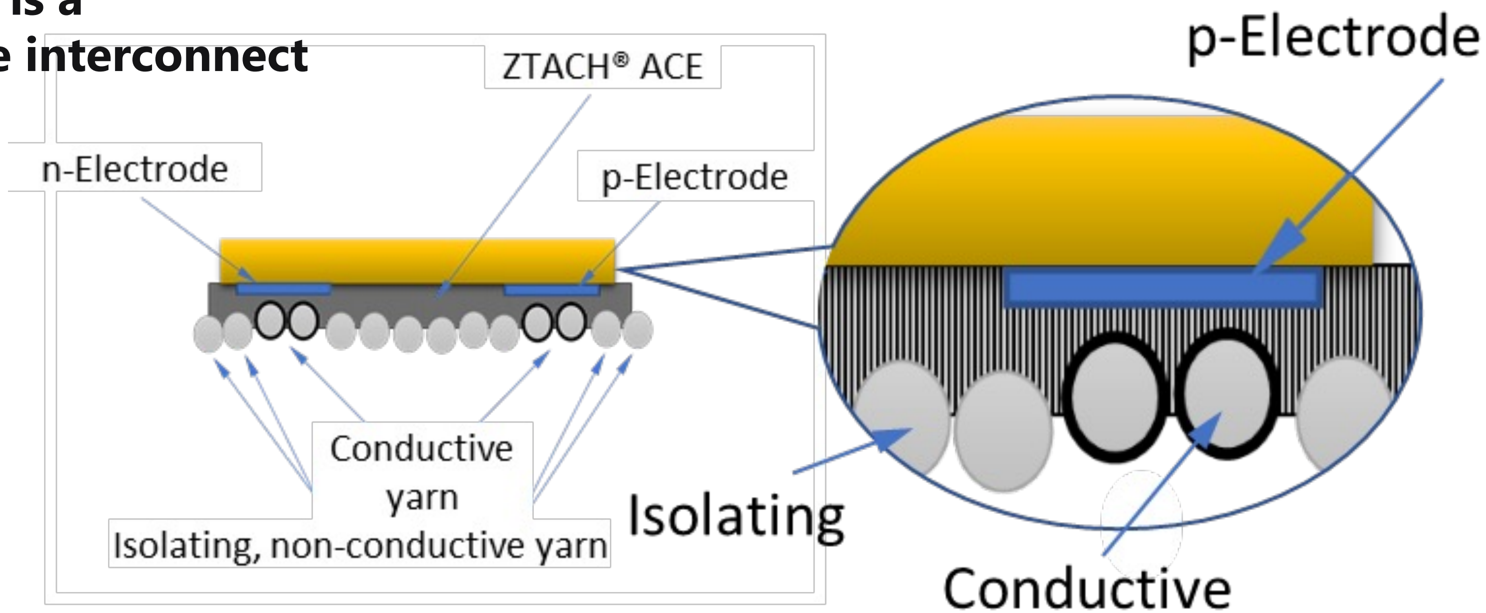
HUMAN SYSTEMS INTEGRATION GE Research NEXTFLEX CAMM

CASE STUDY FHE: ZTACH® ACE IN FLEXIBLE WEARABLES



ZTACH® ACE is a more flexible interconnect



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CASE STUDY: FHE ADVANCED HIGH-VOLUME MANUFACTURING OF HIGH COMPONENT MIX PRODUCTS

Objective:

Integration of additive copper metal with SunRay Scientific's **ZTACH® ACE**, Thermal and UV curable

Produce and demonstrate functionality, durability, reliability, and producibility of **ZTACH® ACE FHE High Intensity LED Light Sheet**

- Compare versus solder

Funded By: NextFlex Project Call 6.8 "Scalability of Multifunctional ZTACH® ACE FHE LED Electroactive Light Sheets for Aerospace Applications", Molex "Semiflex Molex Mixed Mode Interconnects"

Approach:

Replicate a repeatable, automated process optimized for Thermal and UV cured **ZTACH® ACE** at SunRay on Molex SMT lines

SunRay placed SMT LEDs using **ZTACH® ACE** on Molex printed sheets. Auburn University did same with solder

Electro-optical characterization and electromechanical tests performed

Accomplishments:

ZTACH® ACE outperformed other ACA and low temp solder materials

- All components remained adhered and intact, with no Glob Top/encapsulant
- Visual inspections could not identify reason for any failures

LED circuits tested in the fold condition (see picture to left)

- Dynamic flexing under continuous operation
- 30,000 cycles and 20 mm diameter
- RT, 50°C, 100°C &120°C & aging of 30, 60 and 90 days

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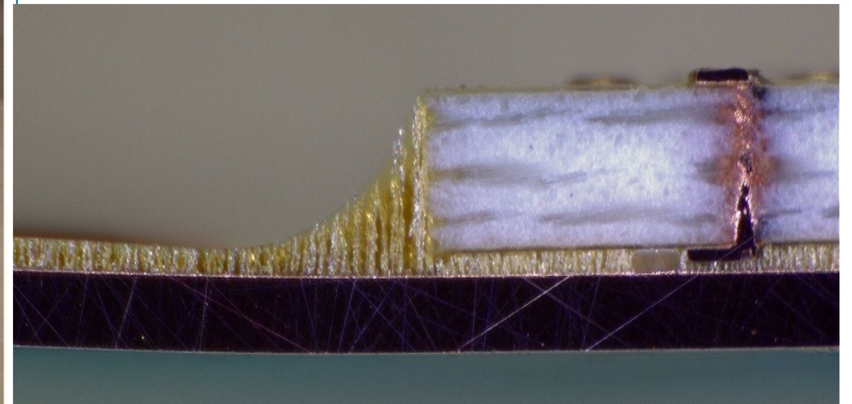
semi FlexTech ARL RIT molex AUBURN UNIVERSITY

ZTACH® ACE – FHE - DYNAMIC FLEXING AND STRETCHABLE APPLICATION DEMONSTRATION

Showing the Robustness and Versatility of the Connections



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ZTACH® ACE – R&D Roadmap
Semiconductor Packaging

Area of Focus	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
Complete Production qualification for customer applications - Printed Electronics/FHE						
Through Glass Via (TGV) fill and interconnection with ZTACH ACE						
ZTACH® ACE – Improving thermal conductivity						
Chiplet Assembly and Injection Molded Solder (IMS) technology for ZTACH ACE						
Achieving finer pitch down to <20 microns						
Understanding and improving power requirements for fine pitch applications						
5G/6G – Enabling various RF Frequencies 1-100+Ghz						
FOWLP onto flex						

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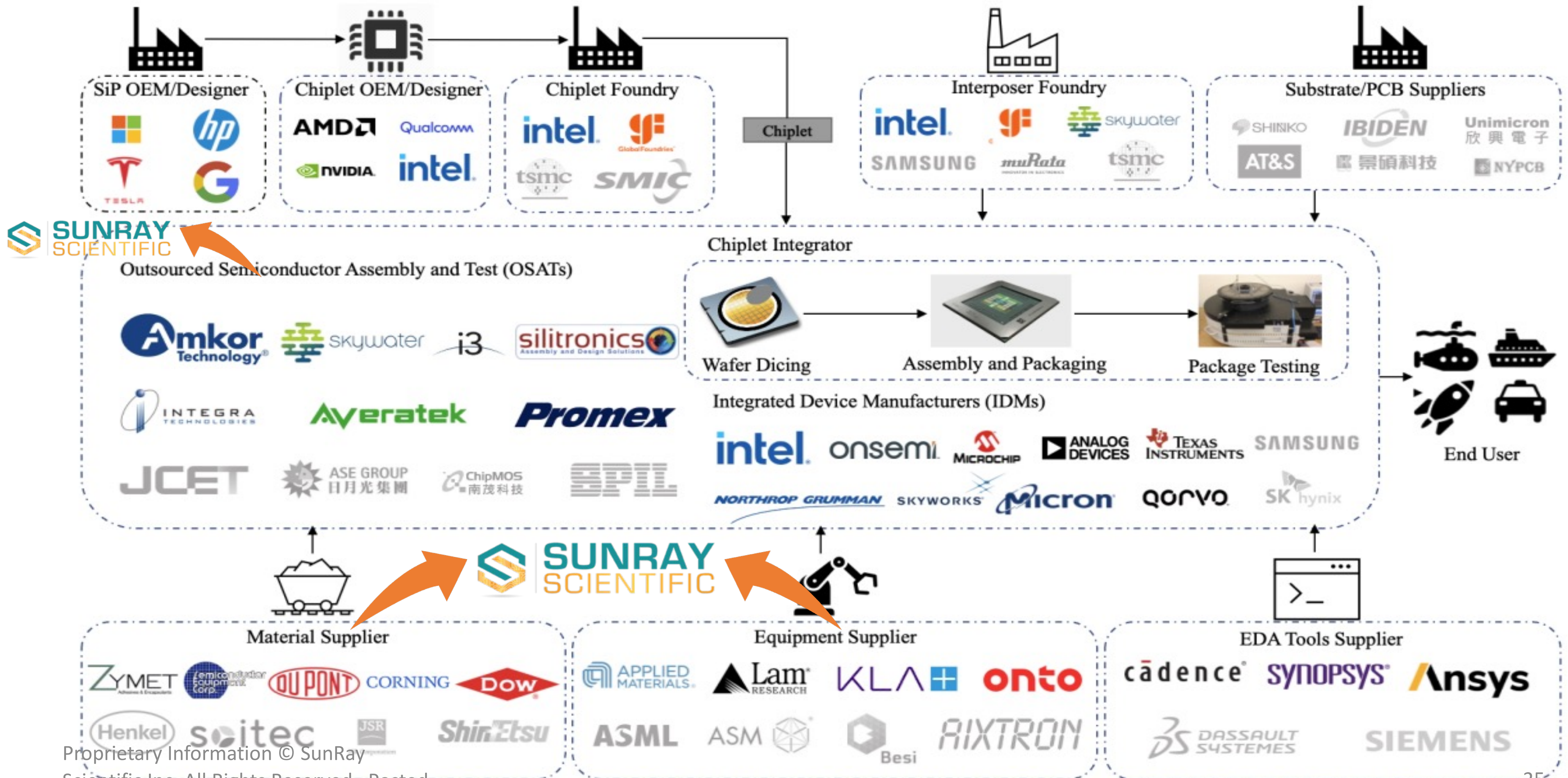
ZTACH® ACE – FIT WITHIN SEMICONDUCTOR PACKAGING ECOSYSTEM LOOKING FOR PARTNERSHIPS TO COLLABORATE



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Source: "US Microelectronics Packaging Ecosystem Challenges and Opportunities", Rouhan Noor, et., al.

THANK YOU

QUESTIONS?

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